

Pacific Northwest and Alaska
Regional Bioenergy Program
Montana Project Summary

1. **Title:** *Biomass Alternatives for Snowmobiles: Emissions Testing and Demonstration of Bio-based Options for Emissions Reduction in 2-Stroke Snowmobile Engines in Yellowstone National Park, Snowmobile in the Park*

2. **Brief Description:** This project provides data and a demonstration of bio-based fuel and lube options for reducing potential pollution and health problems caused by snowmobiles in Yellowstone National Park (YNP). Laboratory emissions tests compared the effects on emissions of biomass-based fuel and lubrication oils used in snowmobile engines to those emissions from conventional fuel and lubes. A bio-based 10-percent ethanol blend was used as a fuel. Lubrication oils include animal and plant fats and their derivatives, such as Conoco's Bio-Synthetic 2-Cycle Oil. Products that reduced emissions and health concerns, show increased biodegradability and efficiency and met manufacturers specifications were demonstrated in YNP for three winter seasons. Industry representatives and others feel that the project is helping set policy for the use of snowmobiles in Yellowstone and the surrounding public lands. If successful, the project ultimately will reduce pollution without undue regulations and provide a market for a new value-added industry.

ABSTRACT of Laboratory testing: Snowmobile engine emissions were becoming a health and environmental concern in environmentally sensitive areas, such as Yellowstone National Park (YNP). A program was undertaken to evaluate potential emission benefits of use of biomass-based fuels and lubricants in snowmobile engines. Candidate fuels and lubricants were evaluated in a laboratory using an air-cooled, 488 cc, carbureted Polaris engine, and a water-cooled, 440 cc Arctic Cat engine. Fuels tested include a reference gasoline (Indolene), gasohol (10% ethanol), and an aliphatic gasoline. Lubricants evaluated include two biomass-based lubricants, a high polyisobutylene (PIB) lubricant, and conventional, mineral-based lubricants. Emissions and fuel consumption were measured using a five-mode test cycle that was developed from analysis of snowmobile field operating data. The use of 10 percent ethanol blend was found to reduce hydrocarbons by 16 to 25 percent, particulate by about 25 to 30 percent, and carbon monoxide by 9 to 20 percent, depending on engine technology. The use synthetic lube oil largely affected particulate matter with reductions of 25 to 70 percent when using 10 percent ethanol blend. Bio-based lubes were found to reduce carbon monoxide by 25 to 38 percent, and hydrocarbons by 16 to 38 percent. The field demonstrations verified that these products work to reduce visible smoke, increased mileage, and also prevented spark plug fouling and carburetor freeze-ups. Engines using a combination of low-emission lube oil and ethanol blend were much cleaner, and had less wear compared to engines using conventional products. As a result of these findings, NPS now uses ethanol blend fuel in their gasoline fleet on a year-round basis. Snowmobile rental operators in West Yellowstone all use ethanol blend and low-emission lube oil voluntarily. The data from these studies is being used by industry manufacturers and EPA to develop cleaner snowmobiles.

3. **Identification** Number: DE-FG51-95R020683, 2ST.104.01 SNOWSUM.WPD
4. **Contractor/Grantee:** Montana Department of Environmental Quality (DEQ)-PPB
1520 East Sixth Avenue, P. O. Box 200901, Helena, Montana 59620-0901
Contact: Howard E. Haines, Bioenergy Engineering Specialist, Planning, Prevention, and Assistance Division, 406-444-6773, FAX 406-444-6836, E-mail hhaines@state.mt.us
5. **Program Manager:** Jeffrey W. James
U. S. Department of Energy Seattle Support Office
800 Fifth Avenue, Suite 3950, Seattle, WA 98104
Phone 206-553-2097, FAX 206-553-1300
6. **U. S. Department of Energy Regional Bioenergy Program Funds:** (1995) \$100,000
Estimated total cost: \$ 564,000

7. Cost Sharing and Project Participants:

Montana Department Environmental Quality (DEQ)	\$ 80,000
Wyoming Department of Commerce, Energy Office	\$ 10,000
U. S. DOE Clean Cities Program	\$ 15,000
U.S. Department of the Interior, National Park Service (NPS)	
Yellowstone National Park and Air Resources Division	\$100,000
International Snowmobile Manufacturers Association (ISMA)	\$195,000
CONOCO, Inc.	\$ 27,000
International Association of Snowmobile Administrators (IASA)	\$ 1,000
Montana Snowmobile Association (Distribution)	
Renewable Fuels Association	\$ 4,000
Southwest Research Institute	\$ 26,000
Ethanol Producers and Consumers of Montana	\$ 3,000
West Yellowstone Chamber of Commerce	\$ 3,000
Allen Oil Company	

Others participants include:

- Ace Snowmobiles, West Yellowstone
- Arctco (Arctic Cat)
- Bombardier Corporation, SeaDoo/SkiDoo Division
- Castrol Oil Inc. and Rotax Engine
- Canyon Street Exxon, West Yellowstone
- Clyde's Service Station, West Yellowstone
- Oronite Additives, Chevron Inc.
- Hi Country Snowmobile Rental, West Yellowstone
- Polaris Industries Inc.
- Rendezvous Snowmobile Rental, West Yellowstone
- Three Bears Lodge, West Yellowstone
- Travelers Service Center & Snowmobile Rental
- Torco International Corporation
- Stage Coach Inn, West Yellowstone
- SnoWest Magazine
- West Yellowstone Conference Hotel and Rentals
- Westgate Service Station and Rentals
- Yamaha Motor Corporation, U.S.A.
- Yellowstone Adventures/Ski Doo, West Yellowstone
- Yellowstone Arctic Cat Yamaha, West Yellowstone
- Yellowstone Snowmobiles

8. Expanded Description: The goal of this project is to reduce potential health and environmental problems caused by snowmobiles in and around Yellowstone National Park. These problems raise the possibility that snowmobiling in the Park may eventually be regulated or even curtailed in some way. Actions taken by NPS regarding snowmobiles will have a significant impact on gateway communities. This project has applicability beyond the Yellowstone region for other areas characterized by valley topography and areas with a tendency for winter inversions. The project is expected to help set public policy for snowmobiles in Yellowstone and Grand Teton national parks and the seven adjoining national forests. The project may contribute to the upcoming rulemaking on snowmobiles by the U.S. Environmental Protection Agency (EPA).

The project first developed emissions and performance data in a laboratory setting at Southwest Research Institute using two common types of snowmobile engines and an industry approved test protocol based on typical U.S. field use. The lab report described the performance, emissions and air toxics from conventional and biomass-based fuel and lubrication oils. Indolene, an emissions-grade gasoline, gasohol (a 10 percent blend of bio-based ethanol with gasoline), and an aliphatic gasoline were used as fuels.

Engine lubrication oils examined a representative sample of the 52 commercial formulations that are currently available or may be available soon. Those tested included Arctic Extreme (as the conventional oil), a highly biodegradable oil --Conoco's Bio-Synthetic 2-Cycle Oil (mostly derived from animal and plant fats), a synthetic biodegradable oil with solvent, Castrol's (Rotax XPS) Biodegradable Synthetic Lubrication Oil, and a fully synthetic, petroleum-based, non-biodegradable, low-particulate oil with a high concentration of poly isobutylene (PIB)--Torco Synthetic Smoke-Less 2-Cycle Oil.

Preliminary findings were shared in a series of meetings between DEQ and ISMA (July 1997), the Idaho Division of Environmental Quality and Idaho Department of Parks and Recreation (July 1997), the Montana Snowmobile Association Board of Directors (September 1997), Minnesota Pollution Control Agency (November 1997), and others. The meetings helped identify the potential user's needs and to clarify points for the draft report. The meetings also provided potential users with enough information to encourage their use of the products the next season.

Laboratory results indicated the benefits of the products that were demonstrated in the fleet of 99 National Park Service snowmobiles. The field demonstration by NPS snow machines used products that showed high biodegradability and efficiency, reduced hazards to health and environment, met manufacturers specifications, and reduced smoke, odor, and noise. The pilot demonstration was conducted with the NPS snowmobile fleet occurred during both the 1995-1996 and 1996-1997 seasons. They used a bio-based lube oil--Conoco's Biosynthetic 2-Cycle Engine Oil. This oil was used because it 1) met the criteria of NPS biodegradability and reduced carbon monoxide, and 2) met snowmobile manufacturers requirements. The 1997-1998 snowmobile season expanded its demonstration to include 10 percent ethanol blend.

Data collected during the field demonstrations included fuel and lube oil consumption, mileage, maintenance, and subjective comments of snowmobile operators and Park visitors. Ambient air monitoring and analysis was conducted continuously for particulate matter in West Yellowstone. Ambient air sampling of select pollutants was done the first winter, and again at heavy use periods during the field demonstration. Permanent glacier snowpack was sampled for 40 metallic ions, total organic carbons, sulfates, nitrates, and ammonia left by emissions during in 1996 and 1998. The 1998 samples were analyzed for select hydrocarbon species. Both sets of snow samples were collected in trails with heavy, moderate, and light snowmobile use. Samples also were collected 100 meters distant from the trails. (This work is being reported by USGS and NPS in cooperation with DEQ, USFS, and Montana Fish, Wildlife and Parks.)

9. **Needs Addressed:** Officials at Yellowstone National Park have documented health and environmental problems caused by 2-stroke engines in snowmobiles. A large percentage of snowmobile emissions results from unburned fuel and lubrication oil consumed with the fuel (about 5 percent of the fuel is motor lubrication oil, and 20 to 33 percent of this fuel is emitted unburned into the atmosphere). Ethanol blends are expected to reduce CO emissions. Data from the European countries shows that commercially available biomass-based lubrication oil can reduce CO, PM, and HC emissions. Some European countries require that 2-stroke engines use an all-alkane (non-aromatic) gasoline for health reasons. Several bio-based lubrication oils and fuels exist in this country and may find a niche market in tourist-related applications. The project addresses the participants' needs by:
 - Developing data to help set public policy
 - Analyzing/defining a niche market for agricultural (biomass-based) products.
 - Defining benefits, tradeoffs and concerns related to use of bio-based products, and
 - Demonstrating results to encourage use by all.
10. **Project Objectives:**
 - Help NPS and industry develop options to reduce environmental degradation without decreasing visitations to Yellowstone NP or restricting snowmobile use.
 - Support commercialization of biomass-based fuel and lubricants, reducing both dependence upon imported oil and impacts on the environment.
 - Encourage the development, production and use of bio-based products within the region by identifying potential markets.
 - Determine the impacts, benefits and concerns of using bio-based products in environmentally sensitive applications, including the promotion of an emissions test procedure that reflects real-world use.
 - Initiate a cooperative working relationship regarding alternate fuels between government and private sectors.

11. Approach: The project provided detailed data of developing products and will demonstrate alternate fuel options for reducing pollution, smoke, and health concerns caused by snowmobiles. (See Expanded Description and Major Milestones.)

12. Major Milestones:

Milestone 1: June 1996. Project management, obtain and review test cycle approved by the industry, Identify concerns from all participants, identify candidate fuels and lube oils

Milestone 2: July 1997. Conduct Laboratory Emissions Tests: Conduct emissions tests of alternate fuels and lube oils at SwRI using the ISMA test cycle. For two engines, samples will be collected on Criteria Emissions (NO_x, HC, PM, HC, carbon dioxide (CO₂), sulfates and select samples of air toxics (hydrocarbon speciation), ketones, aldehydes, and polycyclic aromatic hydrocarbons (PAH) to develop an emission factor (gm/kWh). Fuels and lubes tested include:

- a) Reference gasoline (Indolene) and conventional lube oil (baseline case)
- b) Gasohol (10% ethanol in gasoline) and conventional lube oil
- c) Gasoline and bio-based lube oil No. 1 (like CONOCO's Bio-Synthetic lube)
- d) Gasohol and bio-based lube oil No. 1 and
- e) Gasoline and bio-based and other lube oils (1 engine, mode 1 (wide-open throttle) only, Bombardier/Castrol biodegradable synthetic 2-stroke oil, and high PIB lube oil--Torco smokeless)

Milestone 3: Field Demonstration of Bio-based Options

Activity A: November 1995 through March 1996. Conduct pilot demonstration using bio based oil in NPS fleet.

Activity B: Modify field demonstration based on emissions tests and previous years' experience. For each year, collect records on fuel and lube oil consumption, mileage, maintenance, etc. Coordinate use with ambient air monitoring.

Activity C: Conduct additional field demonstrations using select options.

November 1996 through March 1997 and November 1997 through March 1998

November through March 1998, depending on funds

Activity D: June-August 1998. Report Results to Participants.

Activity E: June-September 1998. Develop Recommendations and final comparative analyses

Milestone 4: September 1999. Analyses, Reporting and Information Dissemination.

13. Accomplishments, Results and Activities:

The DOE project focused on solving the problems at Yellowstone National Park and West Yellowstone. However, the results of this project will affect the industry and other countries.

A. As a result of the 1995/6 pilot demonstration, the Montana Department of Fish Wildlife and Parks now uses Castrol's (Rotax XPS) Biodegradable Synthetic Lubrication Oil in SkiDoo fleet snowmobiles. Laboratory emissions tests were completed in June 1997. Preliminary findings were discussed with industry and a number of potential users. The meetings were to help clarify the findings for potential users of the data. Several articles were written and distributed (text of one of these articles follows this summary).

B. The effects of biomass-based fuels and lubes were studied under laboratory conditions. A more complete discussion of laboratory findings is attached to this project summary. Alternative fuels and lubricants were tested in both fan-cooled and water-cooled snowmobile engines to determine effects on emissions, fuel consumption, and power. The following laboratory observations were made:

- 1• Ten percent ethanol blend fuel reduced HC (16 percent), CO (9 percent), and PM (25 percent) emissions, and slightly increased NO_x emissions, while maintaining equivalent engine power, as compared to results with reference

gasoline in fan-cooled engines. The liquid-cooled engine was less sensitive to fuel changes than the fan-cooled engine. The rate of particulate matter produced was more than double the rate of the fan-cooled engine. Gasohol reduced CO (6 percent) and particulate matter (3 percent), but increased hydrocarbons (by about 5 percent). Tests were sensitive to changes in ambient air temperature and humidity.

- 2 The aliphatic fuel, while increasing *total* hydrocarbon emissions, yielded the lowest ozone formation potential of the three fuels tested due to its low specific reactivity.
- 3 Lubricant formulation affects PM emission rates. The high PIB Torco Smokeless lubricant created significantly less PM (70 percent lower than conventional lubes when gasohol is used as the fuel) than the three other lubricants tested. The biodegradable lubricants reduced carbon monoxide (by as much as 38 percent with the Conoco oil) and hydrocarbons, while increasing particulate matter.
- 4 Particulate emission levels are influenced by lubrication rate, and may also be influenced by engine design. The fan-cooled engine had significantly higher spark plug seat temperatures and, by inference, cylinder temperatures, and substantially lower PM emissions, than the liquid-cooled engine.
- 5 Toxic hydrocarbon species are present in snowmobile engine exhaust in similar proportions to those observed from other sources such as passenger cars.
- 6 Benzene emissions were considerably reduced with the aliphatic fuel.

C. The laboratory results were presented at area meetings and through several articles. the lab report findings being applied by private industry and individuals in the area -- both in Montana and a few in Wyoming. Basically, these products reduced emissions and increased the market for fuel ethanol and biodegradable lubes as outlined below.

A number of field demonstrations were conducted by public and private fleets during the 1997/8 season. Ten percent ethanol blend (also known as gasohol) could not be provided through the existing NPS contract for fuel with Department of Defense. Fuel ethanol had to be donated if gasohol was to be used for the 1997/98 season. Storage of the fuel ethanol or blended gasohol also proved to be a challenge because no one had tankage for these fuels. The Renewable Fuels Association donated the fuel ethanol produced by Heartland Grain Fuels, Aberdeen SD, and the fuel was stored and delivered to NPS contractors by Allen Oil Company, Helena MT.

1. As a result of this demonstration, the Park Service at Yellowstone has contracted that all its gasoline fuel agreement to provide only ten percent ethanol blend (E-10) in place of gasoline for year-round use. The contractor was selected through their normal solicitation, and E-10 became the only fuel for gasoline-powered NPS vehicles in Yellowstone starting June 1, 1998. AmFac, Yellowstone's primary concessionaire, is also planning to use E-10 in its administrative winter fleet. The Yellowstone Park Service Stations (YPSS) are investigating the feasibility of offering E-10 to the public for the 1998/99 winter season. Conversion of these two concessionaires and the Park Service would change about 3.4 million gallons per year of gasoline to E-10, reducing carbon monoxide emissions by about 207.4 tons per year. Plans may be hampered by changes to the underground tank replacement program now in progress, including the use of a different (E-10) fuel.
2. The private sector in West Yellowstone actively promoted the use of these products through news releases and paid radio announcements. By January 4, 1998, all West Yellowstone snowmobile and snowcoach operators voluntarily used E-10 and environmentally preferred lubes. All service stations in West Yellowstone carried ethanol blend. Ethanol blend also was available at (Conoco Mini-Mart) service stations in Jackson and Cody, Wyoming.
4. Based on the work conducted at SwRI and the information supplied by one of the West Yellowstone snowmobile rental operator (who used about 225 sleds, Polaris Synthetic Plus lube (emissions assumed to be similar to the Rotax XPS Synthetic), Polaris engine fleet averaging 500cc, a little over 800,000 miles traveled, and about 70,000 gallons of gasohol used), we estimated that this fleet alone reduced hydrocarbon emissions in Montana and the Park by about 14.8 tons, carbon monoxide emissions by about 20.3 tons, and particulate matter (less than 10 microns in diameter) by about 324 pounds compared to the use of conventional products. Actual field measurements may vary due to weather conditions (including

temperature). However, the use of 10 percent ethanol blend and synthetic lube oil would be expected to reduce hydrocarbons by 16 to 25 percent, particulate by about 25 to 30 percent, and carbon monoxide by 9 to 20 percent, depending on engine technology. Actual field measurements during February 1999 of over 3,000 sleds entering Yellowstone found that 8 percent ethanol blend reduced carbon monoxide by 7 percent.

D. As a result of the laboratory and field work, DEQ drafted text (attached) and distributed a brochure on how to make snow machines environmentally friendly. The text was distributed by area snowmobilers to visitors, and incorporated with other rules for snowmobiling on their World Wide Web page. The text was used in over 100 newspaper articles nation wide. The brochure was printed with funds from Conoco. Over 4,500 brochures have been distributed in the Yellowstone region during the 1998-1999 season

E. Comments from EPA on the draft final laboratory report were received in May 1998. The final report includes analyses and recommendations as to the best methods to reduce the concerns with snowmobiles in Yellowstone National Park. A paper was presented in September 1997 at the Society of Automotive Engineers meeting on Criteria Emissions, and another on the test procedure in September 1998. The test procedure and validation of the emissions test was inspired by the DOE/DEQ program. These papers are published as SAE papers. The findings and data in the DOE draft report were confirmed by this work and are being used by other agencies as they develop regulations on snowmobiles.

Follow-up Activities

Old questions regarding emissions remain, and new ones developed from this work. The overall understanding of snowmobile emissions is being enhanced with an expansion of the DOE project to provide data for snowmobilers, NPS and EPA. These studies investigate noise, personal exposure to air toxics, and develop possible solutions to winter transportation problems. A series of scientific studies (totaling about \$807,000) was developed to evaluate the questions remaining from laboratory investigations and field demonstrations. By September 30, 1999, all but two studies have final reports completed as summarized in Table 1.

A. This project also helped fuel the Green Gateway Corridors Project where safety and environmentally friendly products will be at service stations along the highways leading to and from the Park. Conoco stations (and later others) will use environmentally friendly products and practices in the Park gateway corridors (Yellowstone, Grand Teton, Glacier, etc). This project was developed during the Greening of Yellowstone Workshop in May 1998, along with two others that follow

1. As a result of discussions at the Greening of Yellowstone Workshop May 1998, Planet Electric of North Hills, California, will work with Goat Technologies, Clyde Park and Livingston, MT, in developing an electric snowmobile for use in Yellowstone area fleets. The sleds would be capable of attaining YNP's speed limit of 45 mph with a range of about 100 miles. The typical snowmobile visitor to Yellowstone averages 91 miles a day. The sled batteries would be recharged with 110 VAC systems, with a quick re-charge rate of 80-89 percent in 12 minutes. A program to test these sleds is developed and has been proposed for the 1999/2000 winter season.

2. Other meetings at the May 1998 Greening of Yellowstone Workshop helped develop a national student design competition for cleaner, quieter, snowmobiles. The competition is now supported by the Society of Automotive Engineers (Tony Androssi). Teton County, Wyoming, would host most of the event including the acceleration and hill climbing event. The emissions competition would be done in cooperation with the community of West Yellowstone and Dr. Don Stedman and Dr Gary Bishop of the University of Denver. Potential sponsors should contact Dr. Lori Fussell, 307-733-9745.

3. The International Snowmobile Manufacturers Association is working with the SAE to review and update the noise test for snowmobiles. Each manufacturer has a sound engineer on the task force in addition to two sound engineers from SAE. The task force is looking at modifying the current SAE test so that it can be used easily under field conditions.

B. Outreach by DEQ persuaded snowmobile rental operators in west Yellowstone to use the alternative products. As an illustration of the results, 225 snowmobiles operated by one rental operator (about one-sixth of the total rental fleet in West Yellowstone) traveled a little over 800,000 miles in the 1997-98 season using 10 percent ethanol blend for fuel and a low-emission lube oil. The rental operator found these products eliminated carburetor freezing complaints and significantly

reduced needed engine repairs (compared to previous years). We estimate that the use of these products reduced potential hydrocarbon emissions in the West Yellowstone airshed by about 14 tons, carbon monoxide by about 20 tons, and particulate matter by about 320 pounds.

C. During the winter of 1998/99, the DEQ, DOE, NPS, Pew Charitable Trusts, University of California-Davis, University of Denver, Southwest Research Institute, USGS, Remote Sensing Inc, California Air Resources Board, West Yellowstone Foundation, Montana State University, University of Montana, and others supported a number of applied research studies to be completed in 1999. These studies investigate a number of questions and concerns related to snowmobile emission reductions in the Yellowstone National Park region. A study by the University of California at Davis is analyzing data on the occupational exposure of NPS staff to snowmobile emissions. The University of Denver developed and tested a low-cost in-field method to measure moving vehicle emissions in winter, and evaluated the effectiveness of ethanol blend in reducing carbon monoxide under field conditions. The U. S. Geological Survey is documenting metal ions and select hydrocarbon emissions found in snow. The Southwest Research Laboratory is investigating the size distribution and chemical composition of particulate matter while Montana State University is measuring them in the field. Montana State University also is studying the effect of bio-based fuels and lubes on the persistence of emissions in the environment. Studies by the University of Montana are documenting visitor concerns regarding air quality, noise, and other winter visitor issues. Finally, Bioeconomics Inc., Missoula, Montana, investigated visitors' willingness to pay for clean snowmobile technology.

D. EPA granted DEQ funds to transfer the results from these studies to snowmobile users, designers, and land managers, to help reduce emissions of the current and future snowmobile fleet. The project will do this by developing informational brochures and materials, support of a clean snowmobile design competition with the Society of Automotive Engineers, and presentation of this health, safety, and environmental information at two workshops.

If negotiations are successful, this new project will initiate partnerships between DEQ and the Minnesota Pollution Control Agency (MPCA), the National Center for Appropriate Technology (NCAT), the Society of Automotive Engineers (SAE), Teton County, Wyoming, the National Park Service, the snowmobile industry, and the EPA Office of Mobile Sources and EPA Region VIII. This grant enables these partners to develop an educational workshop targeted at voluntary public use of pollution-reducing technologies. The workshop will be presented in at least two locations (one will be in Minnesota and the second possibly at the Snowmobile Congress 2000 in New Hampshire). The grant will help support an international clean snowmobile design challenge to be held in March 2000 in the Yellowstone region, and will assist in establishing a regional clearinghouse for these technologies at the National Center for Appropriate Technology. If successful, these efforts will reduce the impacts on air and water quality from the use of 2-stroke snowmobile engines..

Awards, Reports, Papers, Acknowledgments

U. S. Environmental Protection Agency EPA Region VIII. Outstanding Achievement Award to DEQ for Teamwork and Environmental Stewardship in Yellowstone Nation Park as exemplified by the Snowmobile and Truck in the Park Teams, August 27, 1996.

Conoco President's Award to DEQ for the Environment, May 1996.

Top Honors (international) DuPont Award to DEQ for the Environment and Safety.

National Park Foundation 2001 National Park Partnership Award Honorable Mention for Environmental Conservation, April 22, 2001, Washington, D. C.

Reports on Web Sites: <http://www.deq.state.mt.us/ppa/programs.html> Greening of Yellowstone Projects, Emissions and Bio-based fuels <http://www.deq.state.mt.us/ppa/p2/biofuels/biofuels.htm> and Snowmobile Emissions in Yellowstone National Park <http://www.deq.state.mt.us/ppa/snowmobl/snowmobl.htm> www.nps.gov/renew/ under case studies, Yellowstone NP <http://www.nps.gov/renew/yellbio.htm>

White, Jeff J., James N. Carroll, Howard E. Haines. October 1998. **Emissions from Snowmobile Engines Using Bio-based Fuels and Lubricants Final Report**. Montana Department of Environmental Quality, Helena, Montana.

White, Jeff J., James N. Carroll, Howard E. Haines. October 1997. **Emissions from Snowmobile Engines Using Bio-based Fuels and Lubricants**. Small Engine Technology Conference JSAE 9734412, SAE 972108. Society of Automotive Engineers of Japan, Yokohama, Japan.

Wright, Christopher W., Jeff J. White. September 1998. **Development and validation of a snowmobile Engine Emission Test Procedure**. International Off-Highway & Powerplant Conference and Exposition SAE 982017. Society of Automotive Engineers, Milwaukee, Wisconsin.

Future Activities and Technology Transfer Events

Develop additional funding for follow-up projects, request time extension

15. **Date Prepared:** May 4, 1995
 Date Amended: April 19, 2000

Make Your Snow Machine More Environmentally Friendly - Draft Text

Making a Difference

All snowmobile and snowcoach rental operators in West Yellowstone have agreed that 10 percent ethanol blend is an environmentally friendly product to use. Most will use 10 percent ethanol blend this winter to protect air and water quality in Yellowstone Park and vicinity. Most snowmobile rental operators in West Yellowstone also will be using synthetic lube oils shown to reduce pollution. The Park Service will use 10 percent ethanol blend and a synthetic biodegradable lube in its snowmobiles in Yellowstone. The use of 10 percent ethanol blend and synthetic lube oils by rental operators and the Park Service will reduce snowmobile carbon monoxide emissions by 9 to 38 percent, and particulate emissions by 24 to 55 percent, compared to previous years. Further, service stations in West Yellowstone, Montana, and Cody and Jackson, Wyoming have committed to making oxygenated fuel available to the general public for all private vehicles. Snowmobilers in the Yellowstone area are encouraging visiting snowmobilers to join the effort and use oxygenated fuels and synthetic low emission lube oils when in the area. This should reduce any potential health hazards, especially to children, pregnant women, older people, people with cardiovascular disease and those with impaired lung function such as asthma sufferers.

Checklist to Make Your Snow Machine More Environmentally Friendly

- use proper jets, keep engines tuned and clutches adjusted properly for the elevation where machines operate
- use oxygenated fuels such as "10 percent ethanol blend" to reduce pollution
- use synthetic low-particulate lube oils to reduce particulates and smoke
- use synthetic biodegradable lube oils to reduce potential health and environmental problems
- check with your dealers, outfitters, and/or retailers for availability of these and similar products

For more detailed information and follow-up activities, see www.deq.mt.gov/ppa/index.htm (Under Planning, Prevention and Assistance Division PROJECTS, click on either "Yellowstone Snowmobile Emissions for a general article or click on "Bio-based Fuels and Emissions" for the technical report) or contact Montana Department of Environmental Quality at 406-444-6773, or e-mail hhaines@state.mt.us.

Background

In recent years, the burgeoning popularity of snow machines in and around Yellowstone National Park has led to concerns about the possible environmental effects of this winter recreation. Winter use by snowmobilers in the park increased from 45,000 visitors in 1986 to about 85,000 in 1994, the most recent year of uninterrupted snowmobile use. The particular conditions in Yellowstone, including the dense, cold, often stable air, in combination with the specific emissions from snow machine engines, have the potential to produce unacceptable impacts to the environment.

Air Quality and Environmental Problems

Both Park Service personnel and visitors have expressed concern about haze, carbon monoxide, and odors of exhaust in areas of heavy snow machine use in Yellowstone. These problems are especially noticeable along roads to Old Faithful. Emissions from snow machines include carbon monoxide, hydrocarbons, particulate material, and a variety of gases classified as "air toxics." Poor air quality detracts from the quality of visitor experience and can be a health hazard.

Some Solutions

Emissions from snowmobiles can be minimized by keeping the engines tuned properly for the elevation where they are operating. The high altitude of Yellowstone, ranging from 6,600 to 8,500 feet along the roads traveled by snow machines, requires carburetor jets with smaller orifices than would be used at lower elevation. Use of the smaller jets results in more complete fuel combustion. Installation of proper jets for higher elevation also improves engine performance, and snowmobile clutches should be adjusted to match performance. These adjustments usually must be made by a qualified mechanic. Proper clutch adjustment also reduces fuel use and emission of pollutants.

Another promising method for reducing emissions is the use of oxygenated fuels and specially formulated lube oils. The oxygenated fuel used in Montana is 10 percent ethanol blend which consists of 10 percent ethanol and

90 percent conventional gasoline. Use of 10 percent ethanol blend and other oxygenated fuels reduces emissions of most harmful pollutants from gasoline engines in both snowmobiles and snowcoaches.

Various manufacturers of low-emission 2-cycle oil combine various characteristics into their formulations. Testing funded by the Montana Department of Environmental Quality (DEQ) and others compared emission levels from a conventional petroleum-base lube oil to those from three oils formulated to improve performance and reduce emissions. These were: Conoco Bio-Synthetic 2-Cycle Engine Oil, which is highly biodegradable; Bombardier Rotax (Castrol) Formula XPS Synthetic Two-Stroke Oil (a synthetic biodegradable lube with solvent) which is biodegradable and produces lower particulate emissions; and TORCO Synthetic Smoke-Less 2-Cycle Oil, a fully synthetic lube oil that is low particulate but not biodegradable.

Test results show that the use of synthetic low-particulate oils significantly reduces pollution. Synthetic biodegradable lube oils reduced carbon monoxide, and probably would reduce any potential impacts to water quality. Snowmobilers should check with their dealers, outfitters, and/or retailers for availability of these products, which will become more available in the near future. For more detailed information on the use of ethanol blend in your machine, see Understanding Ethanol in **Snowmobile** magazine, October 1997.

Table 1. Winter Science Studies: Transportation and Visitation in Yellowstone Region				
Study Title	Principal Investigator	Resource studied and need	Cost	
1. *Characteristics of Snowmobile Particulate Emissions with bio-based lube	Southwest Research Institute	Particulate emissions: determine size, chemistry, diesel comparison & tradeoffs	\$39,500	
2. ****Field Studies of Aerosol Formation and Biodegradation of Snowmobile Fuels, Lubricants and Emissions in the Yellowstone Region	Drs Bonnie Tyler, Richard Peterson, Montana State University	Define benefits & applicable stds for biodegradable, non-toxic cold climate fuels, lubes. Air vs water quality benefits	\$87,191	
3. *Measurement and Bioassay of Airborne Toxics and Regulated Pollutants from Snowmobiles	Drs N Kado, Paul Kuzmicky, University of California, Davis	Emissions and select air toxics in conjunction with reported health effects in park service personnel (OSHA)	\$183,000	
4. ***Snowmobile Emissions: (in-field measurement of) the effects of ethanol-based fuels	Drs Stedman, Gary Bishop, University of Denver	Develop and demonstrate a lowcost field method to (IR) monitor criteria emissions	\$45,600	
5. *Snowpack and snowmelt runoff chemical analysis, YNP and Montana	Dr George Ingersoll, U. S. Geological Survey	Relationship between trail use, major ions & metals, in snowpack and spring runoff	\$54,560	
6. **Field Evaluation of Gasohol's Ability to Reduce Snowmobiler Exposure to CO in Yellowstone	Dr L Fussel	Statistically valid exposure levels of CO and select emissions for ethanol-blends for high, medium- low- trail use	\$135,320	
7. *Social Carrying Capacity of YNP for Winter Use	Drs William Borrie, Wayne Freimund, University of Montana, Dr Robert Mannin, Univ of Vermont	Social indicators of carrying capacity of visitors (visitor concerns about emissions, congestion) and reductions in travel congestion	\$62,000	
8. Air Quality Monitoring,	MT DEQ, YDEQ, NPS	PM-10, CO	\$200,000	
Total Costs			\$807,171	
*Pew Charitable Trusts			\$160,000	
**Interscan Foundation			\$58,660	
***Remote Sensing Technologies Inc West Yellowstone, ISMA, and DOE WRBEP			\$46,190	
****DEQ, DuPont, Conoco, NSF			\$246,191	
National Park Service			\$180,000	
Total unfunded (Projects 2 and 3)			\$116,130	

RESULTS AND DISCUSSION

REGULATED EMISSIONS - Five-mode cycle emissions and fuel consumption from the Polaris engine are shown in Table 6. HC, CO, and PM emissions are high, and NO_x emissions are low, as is typical of 2-stroke engines. Emissions are comparable to previously reported results with allowance for differences in engine operation and test procedure.

The RICH test generated significantly higher HC, CO, and PM emissions (20%, 14%, and 28%, respectively), than the mean gasoline baseline result. Fuel consumption also increased by 13 percent, and Mode 1 (wide-open throttle, WOT) power decreased by 14 percent. This test was run with a richer than specification main jet to simulate the effect of operating a snowmobile at a higher altitude than originally calibrated for. The difference between the normal (210) and richer (240) jet corresponds roughly to an 1800 m (5906 ft.) altitude difference, and confirms that incorrect jetting significantly increases snowmobile engine emissions.

Test A12 examined emissions with the CONOCO Biosynthetic lubricant and reference gasoline. Results were similar to those generated with the reference lubricant (ARCTIC Extreme), except for particulate matter, which increased 66 percent. This may be related to the lower front end volatility of the CONOCO lubricant compared to the reference lubricant as observed in the distillation results in Table 2.

The 10 percent ethanol blend results indicate substantial emission benefits may be obtained using an oxygenated fuel in snowmobiles. Test A21 (gasohol with reference lubricant) produced 16 percent less HC, 9 percent less CO, and 24 percent less PM than the mean gasoline baseline result. Specific fuel consumption was also reduced, and Mode 1 power was maintained or possibly slightly increased, from base gasoline levels. The 10 percent ethanol blend test run with the CONOCO lubricant (A22-1) resulted in 64 percent more PM than Test A21 with the reference lubricant, confirming the increased PM observed in Test A12. The 10 percent ethanol blend/CONOCO test also produced less HC and CO than the 10 percent ethanol blend/ARCTIC Extreme test; however it is unlikely that this was due to a lubricant change. HC and CO reductions were not observed in the gasoline-based comparison between these lubricants, and it is more likely that these emissions differences reflect engine drift between tests.

Aliphatic fuel results reflected increased HC and PM results (33% and 47%, respectively), compared to the mean gasoline baseline result. Fuel consumption also increased, and Mode 1 power was reduced about 5 percent.

Engine emissions were not as repeatable as we would have liked. Steep engine power output characteristics, coupled with the less precise control of the waterbrake dynamometer made it difficult to achieve precise control of modal setpoints. To try to obtain a more accurate comparison of lubricant effects, three lubricants were run back-to-back in Mode 1 (WOT) operation without shutting the engine off or making any adjustments. After switching lubricants, the engine was operated for a sufficient length of time to flush the injection system with the new lubricant prior to taking emission data. Gasohol was selected as the fuel for this comparison because it provided lower emissions than the reference gasoline. Results are summarized in Table 7.

Differences in HC, CO, and NO_x emissions are small, and likely not significant. These results are consistent with 5-mode results which showed significantly higher PM emissions with the CONOCO lubricant. As a point of reference, Mode 1 PM emissions in the 10 percent ethanol blend/ARCTIC Extreme test (A21) were 0.27 g/kW-h, similar to results observed with the CASTROL lubricant. The TORCO Smokeless lubricant emitted 43 percent less PM than the CASTROL, which suggests that the use of this material could decrease the visible haze associated with snowmobile engine operation.

Five-mode cycle test results with the Arctco engine are presented in Table 8. To obtain better engine control, an eddy-current dynamometer, fitted with a belt-driven speed reduction system, was used for this engine. See Figure 3. This approach provided much better control than the water-brake dynamometer used with the Polaris engine. Speed and load setpoints were maintained typically within a few percent of set value. In spite of this, variability between repeat Arctco tests W11-1 and 2 was not substantially decreased compared to Polaris results. This may be due to the type of carburetion employed with these engines, which uses three different circuits to control fuel delivery. Emission rates appear to be highly sensitive to small changes in engine operation, particularly at the more heavily weighted part-throttle modes.

The water-cooled Arctco engine also showed reduced emissions using 10 percent ethanol blend, although it was less sensitive to fuel differences than the Polaris engine. With 10 percent ethanol blend, HC, CO, and PM were reduced 7 percent, 6 percent, and 3 percent, respectively. Oxides of nitrogen emissions increased 6 percent, and specific fuel consumption was reduced 3 percent. Mode 1 WOT power with 10 percent ethanol blend was equivalent to or slightly greater than with gasoline. Improvements in power and fuel economy are due to the rich base calibration established for

gasoline. Enleanment provided by the oxygenated fuel appears to improve the quality of combustion in these engines, yielding reduced emissions and increased power at equivalent fuel flows.

Emission rates of HC, CO, and NO_x were fairly similar for the two engines tested. Particulate emission rates, however, were much higher with the Arctco engine. An examination of lubrication rates (fuel/oil ratio) (Table 9) showed that the Arctco engine ran 3 to 18 percent more oil rich than the Polaris engine, except in Mode 5 (idle) where the Arctco engine lubrication rate was more than three times that of the Polaris engine. These differences, however, are insufficient to account for the magnitude of the PM difference. Further investigation suggested an additional factor. Spark plug seat temperature data showed that there were large differences in cylinder temperatures between air-cooled (Polaris) and water-cooled (Arctco) designs. Polaris spark plug seat temperatures were typically 180 C higher in Mode 1, than those with the Arctco engine, and it is likely that these higher cylinder temperatures promote more complete volatilization of injected lubricant, resulting in lower PM emissions.

SPECIATED EMISSIONS - Hydrocarbon speciation was performed on selected tests using the three GC Auto/Oil procedure, which identifies and quantifies 223 individual C₁-C₁₂ hydrocarbons. Results may be analyzed in a variety of ways depending on specific properties of interest. Organic gases may be classified according to hydrocarbon type, such as paraffin, olefin, aromatic, carbonyl, and other. Toxic or other target species emissions rates can be examined. Since the regulation of organic gas emissions is due to their role in ozone formation, speciation results are often analyzed to determine ozone formation potential, based on application of species-specific Maximum Incremental Reactivity (MIR) values. Selected Polaris engine speciation results are presented in Table 10. Total speciated hydrocarbons are compared to THC levels determined by FID. Agreement between the two methods is quite good with GC levels ranging from 90 to 101 percent of FID HC levels.

Four organic gases have been classified by EPA as toxic species - 1,3-butadiene, benzene, formaldehyde, and acetaldehyde, and these are also shown in Table 10. Emission rates of 1,3-butadiene are fairly similar among the different fuel/lubricant combinations. Benzene emissions were considerably less with the aliphatic fuel, as would be expected with its low level of aromatics. It appears that some benzene is being produced in the combustion of this aliphatic fuel, perhaps through thermal cracking and reformation. Formaldehyde emissions are slightly higher with both 10 percent ethanol blend and aliphatic fuel than with gasoline. Acetaldehyde emissions are also increased with the ethanol containing fuel, as expected, since the ethyl group is a direct precursor of acetaldehyde, and may be readily converted to acetaldehyde through partial oxidation.

Overall, toxic species appear to be present in similar proportions to those observed from other sources. For example, 1,3-butadiene, benzene, formaldehyde, and acetaldehyde were present in gasoline-fueled Polaris engine exhaust at levels of 0.14, 0.80, 0.64, and 0.10 percent, respectively of total hydrocarbon emissions. These levels are similar, percentage wise, to those observed in older catalyst and non-catalyst equipped passenger cars. (8)

Ozone formation potential was reduced 15 percent with 10 percent ethanol blend, compared to gasoline results. The aliphatic fuel provided an even greater reduction (22%) in spite of its higher *total* hydrocarbon emissions. This is due to the lower composite reactivity of species emitted. Fuel characteristics may also be viewed in terms of specific reactivity, which is equivalent to total ozone formation potential divided by total hydrocarbon levels. Specific reactivities for 10 percent ethanol blend tests were 3 percent higher than with gasoline. With aliphatic fuel, specific reactivity was 25 percent less than with gasoline. These values reflect a slightly higher composite exhaust reactivity with an ethanol-containing fuel, and a significantly lower composite reactivity with the aliphatic fuel. While these data suggest some important benefits which could be provided by aliphatic fuels, ozone formation potential is likely of less concern than CO (and HC) emissions in a winter-use scenario.

SUMMARY AND CONCLUSIONS

Alternative fuels and lubricants were tested in both fan-cooled and water-cooled snowmobile engines to determine effects on emissions, fuel consumption, and power. The following observations were made:

- 10 percent ethanol blend reduced HC, CO, and PM emissions, and slightly increased NO_x emissions, while maintaining equivalent engine power, as compared to results with reference gasoline.
- The aliphatic fuel, while increasing *total* hydrocarbon emissions, yielded the lowest ozone formation potential of the three fuels tested due to its low specific reactivity.
- Lubricant formulation affects PM emission rates. The high PIB TOROCO Smokeless lubricant created significantly less PM than the three other lubricants tested.

- Particulate emission levels are influenced by lubrication rate, and may also be influenced by engine design. The fan-cooled engine had significantly higher spark plug seat temperatures and, by inference, cylinder temperatures, and substantially lower PM emissions, than the liquid-cooled engine.
- Toxic hydrocarbon species are present in similar proportions in snowmobile engine exhaust to those observed from other sources such as passenger cars.
- Benzene emissions were considerably reduced with the aliphatic fuel.

Promising candidates are being recommended to the National Park Service for further evaluation in a field demonstration to be conducted this winter in Yellowstone National Park.

Table 1 **Polaris Engine - 5-Mode Cycle Emission Test Results**

Fuel	Lubricant	Test ID	Emissions , g/kW-h				BSFC, kg/kW-h	Mode 1 kW
			BSHC	BSCO	BSNOx	BSPM		
Gasoline	ARCTIC	A11-3	223	589	0.61	2.13	0.68	43.8
Gasoline	ARCTIC	A11-4	180	526	0.56	1.49	0.60	46.2
Baseline Gasoline (mean)			202	558	0.58	1.81	0.64	45.0
Gasoline	ARCTIC	RICH	241	635	0.42	2.31	0.72	38.9
	RICH/Baseline		120%	114%	72%	128%	113%	86%
Gasoline	CONOCO	A12	199	537	0.57	3.01	0.62	45.9
	A12/Baseline		99%	96%	97%	166%	97%	102%
Gasohol	ARCTIC	A21	170	506	0.59	1.38	0.60	46.1
	A21/Baseline		84%	91%	101%	76%	93%	102%
Gasohol	CONOCO	A22-1	140	445	0.59	2.26	0.54	46.9
Aliphatic	ARCTIC	A31-1	245	552	0.63	2.53	0.70	42.1
Aliphatic	ARCTIC	A31-2	292	586	0.68	2.80	0.76	43.4
Mean Aliphatic			268	569	0.66	2.66	0.73	42.8
Aliphatic/Baseline			133%	102%	112%	147%	113%	95%

Table 2. Laboratory Analysis of Lubricants

Property			CONOCO Biosynthetic	CASTROL XPS	TORCO Smokeless
Specific Gravity	ASTM D-4052	0.8676	0.9265	0.8958	0.8598
Viscosity @ 40 C, cSt	ASTM D-445	24.16	55.62	41.23	43.24
Viscosity @ 100 C, cSt	ASTM D-445	5.01	9.05	8.78	7.22
Flash Point, C	ASTM D-92	80	244	104	80
Total Base Number	ASTM D-4739	6.40	1.18	2.99	0.86
Total Acid Number	ASTM D-664	0.71	0.68	0.64	0.25
Carbon, wt. %	ASTM D-5291	84.88	75.52	80.32	86.11
Hydrogen, wt. %		13.63	12.13	12.86	14.20
Nitrogen, wt. %	ASTM D-5291	0.620	0.245	0.253	0.034
Ba, ppm		<1	1	2	<1
Ca, ppm		7	2	588	304
Mg, ppm		<1	<1	4	8
Mn, ppm		<1	<1	<1	<1
Na, ppm		4	3	1	10
P, ppm		3	186	68	9
Zn, ppm		3	1	1	9
Distillation by GC, C	ASTM D-2887				
IBP		141	318	174	140
5%		189	400	194	184
10%		211	469	207	210
20%		250	484	431	250
50%		410	492	561	418
80%		521	605	581	641
90%		648	618	640	684
95%		691	692	673	698
FBP		724	728	727	724

Table 7. Polaris Engine - Mode 1 Lubricant Emission Results

Fuel	Lubricant	Test ID	Mode 1 Emissions , g/kW-h			
			BSHC	BSCO	BSNOx	BSPM
Gasohol	CASTROL	A23	91	387	0.74	0.21
Gasohol	TORCO	A24	97	381	0.80	0.12
Gasohol	CONOCO	A22-2	91	372	0.83	0.64
	TORCO/CASTROL		107%	98%	108%	57%
	CONOCO/CASTROL		101%	96%	112%	305%

Table 8. Arctco Engine - 5-Mode Cycle Emission Test Results

Fuel			Emissions , g/kW-h				BSFC, kg/kW-h	Mode 1 kW
			BSHC	BSCO	BSNOx	BSPM		
Gasoline	ARCTIC	W11-1	199	468	0.68	4.14	0.66	42.5
Gasoline	ARCTIC	W11-2	237	505	0.64	5.11	0.72	42.3
Baseline Gasoline (mean)			218	487	0.66	4.63	0.69	42.4
Gasohol	ARCTIC	W21	203	459	0.70	4.51	0.67	43.0
Gasohol/Gasoline			93%	94%	106%	97%	97%	101%

Table 9. Measured Fuel/Oil Ratio and Spark Plug Seat Temperature Data

Engine			Mode 3	Mode 4	Mode 5
Measured Fuel/Oil Ratio					
Polaris	30	43	46	44	90
Arctco	29	37	38	38	24
Spark Plug Seat Temperature, C					
Polaris	251	166	139	113	70
Arctco	71	66	64	60	54
Polaris data - mean values of A11-3&4					
Arctco data - mean values of W11-1&2					

Table 10. Polaris Engine - 5-Mode Cycle Speciation Results

[illegible]

G:\PPB\BIOMASS\TRANSFER\SIPFIN1.DOC, 08/21/01